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Sustainability and innovation in the Brazilian supply chain of green plastic

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ABSTRACT

Climate change has intensified the demand for better social and environmental conservation efforts, motivating organisations to become more engaged in the development of sustainable technologies. This study analyses the innovation process in the production of green plastic, a process which replaces a non-renewable resource (naphtha) for a renewable one (ethanol from sugarcane), through the lens of sustainable supply-chain management (SSCM). An in-depth case study was conducted with a Brazilian petrochemical company, including interviews with agents of the supply chain. The results show that collaborations between the focal organisation and other agents of the supply chain are important for product development. The focal organisation has created many industry-wide initiatives, such as certification programmes and seal of quality/approval, to support the production of green plastic and reduce the social and environmental impact along the supply chain.

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1. Introduction

Throughout history, the use of natural resources has been central to economic development, generating such benefits as a wider variety of products available for consumption. However, while industrialisation has resulted in progress and modernity, bringing advantages to organisations and social well-being, it has also caused significant social and environmental problems.

The consequences of these production and consumption patterns have led society, particularly private, public and non-profit organisations, to take more intensive action towards sustainability. These consequences have underlaid discussions on sustainable development (SD) from the 1970s, especially those focusing on global warming, greenhouse effects and ocean acidification. These environmental issues, which have been primarily attributed to fossil-fuel burning, has sparked interest in renewable energy sources (Abbasi and Abbasi, 2012; Hall et al., 2014).

Corporations are assuming an increasingly significant role in the quest for sustainability, seeking to minimise the social and environmental impacts caused by production. Innovation is now understood as a way to contribute to SD (Boons et al., 2013; Carvalho and Barbieri, 2012; Jansen, 2003; Matos and Silvestre, 2013; Seyfang and Smith, 2007; Silvestre, 2015a, b; Smith, 2010; Vollenbroek, 2002).

Sustainability-oriented innovation may include renewable resources, reverse logistics, eco-efficiency, green supply chain and the involvement of the entire supply chain. It can also be considered an environmentally friendly business strategy (Hansen et al., 2009; Katsikeas et al., 2016). The use of renewable energy sources provides an alternative to fossil fuels, thereby improving the environment. For example, the petrochemical industry substitutes the

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use of green plastic, which is the topic of the present research.

Green plastic (green polyethylene [PE]) differs from traditional plastic in terms of sustainability, as green PE helps reduce greenhouse gas (GHG) emissions along the production chain. The cultivation of sugarcane, which sources green PE production, also aids in the capture and sequestration of carbon, which contribute to climate change mitigation. Green PE is the first certified plastic made from a renewable source worldwide, making the petrochemical industry a pioneer in this field.

Another concept emerging from green production is sustainable supply-chain management (SSCM). In general, SSCM involves characteristics of business sustainability (i.e. economy, environment, society, stakeholders, volunteers, resilience and long-term goals) and supply-chain management (SCM) (i.e. flow, coordination, stakeholders, relationships, value, efficiency and performance) (Ahi and Searcy, 2013; Diabat et al., 2014). The discussions on innovation, SD and SSCM provide a backdrop for modifications made in the petrochemical production chain over recent years, including the use of raw materials (as renewable energy) for green plastic production. These modifications are especially observed in Brazil, an emerging economy, which has positioned itself as a global leader in sustainable energy and agriculture through technological innovation (Hall et al., 2011).

In consideration of the arguments presented, the present study analyses the innovation process in the production of green plastic, a process which replaces a non-renewable resource (naphtha) for a renewable one (ethanol from sugarcane), through the lens of SSCM. Many previous studies (e.g. Ahi and Searcy, 2013; Carter and Rogers, 2008; Diabat et al., 2014; Dubey et al., 2017; Gosling et al., 2017; Reefke and Sundaram, 2017; Seurer and Muller, 2008; Svensson, 2007) have developed frameworks for the study of SSCM, but each provides only a brief description of the enterprise-led initiatives. The present study applies the concept of SSCM within a specific context: green plastic production by an important organisation in the Brazilian petrochemical industry. In addition, this study aims to demonstrate the importance of engaging supply-chain agents in the sustainable development of the product.

This article is organised into five sections, beginning with the introduction. In the second section, we present the methodology. The third section outlines the theoretical background. In section four, we analyse the results obtained from the data collection. Finally, section five concludes our research and provides recommendations for future studies.

2. Materials and methods

The present study is classified as exploratory and descriptive, focusing on a qualitative approach and using data collected through field research. A case study of a Brazilian petrochemical company that develops green plastic was conducted. To preserve anonymity, the company's name and precise location has been withheld.

There are five main stages in the production chain of green plastic. The first stage consists of sugarcane cultivation. The sugarcane produced is sold to power plants that supply ethanol, which is the second stage. The petrochemical company (the focal organisation) is involved in the third stage of the supply chain. The fourth stage includes manufacturing by third-generation organisations within the plastic industry, which transforms green PE into various products. The fifth stage, which is not analysed in this research, is consumption, which involves wholesalers, retailers and/or the final consumers, depending on the sales strategy of each manufacturing industry.

To better understand the organisational dynamics of the first and second stages, we analysed the Code of Conduct for Ethanol Suppliers of FOs (information gathered from a report by the FO) and other documents and bibliographies related to this issue. Regarding the third and fourth stages of the supply chain, we performed interviews with key informants, which provided information on business strategy necessary to this research. Based on the theoretical background, two scripts were designed for the semi-structured interviews: one for the focal organisation (third stage) and another for the manufacturers (fourth stage). These interviews were conducted in-person and online, depending on the interviewees' availability (Table 1). The average duration of each interview was 65 min.

We conducted interviews with seven agents involved in the supply chain of green plastic. This sample size was determined by the concept of saturation, which refers to when the collection of new data does not add more information related to the issue under investigation (Mason, 2010). The sample size, although low, allowed for a satisfactory overview of the relationships between the agents of the supply chain. The interview transcripts totalled 34 pages. After transcribing the interviews, we organised the material in preparation for the content analysis, which followed three phases: analysis and material exploration, treatment of results and interpretation (Bardin, 2016).

2.1. Green plastic

The present research explores the production of plastic resins as part of the petrochemical industry, focusing on green plastic. Green plastic is also known as green polyethylene (PE), green polymer, biopolyethylene, biopolymer, polymer resin or green resin.

The chemical industry is one of the leading industries worldwide, and the petrochemical sector is one of its most significant components. The global industry of plastic resins is formed by multinational, vertically integrated chemical organisations. The FO under analysis integrates the first (basic petrochemicals) and the second (thermoplastic resins) generations of the production process for traditional and renewable plastics. The FO has a thermoplastic resin and basic chemical production capacity of 16 million tonnes per year (information gathered from a report by the FO).

Global demand for renewable products has initiated the development of innovative products within the chemical industry. Bioplastics, also known as bio-based polymers or biodegradable polymers, are currently available on the market (European Bioplastics, 2016). In Brazil, bioplastic production using sugarcane is possible due to the nation's climatic advantages and the extent of land available for this crop. In response to the debates on global warming and GHG emissions, renewable resources serving as raw material for manufacturing plastics have emerged as an alternative to fossil fuels and assist with carbon-dioxide capture. The FO creates and enhances biodegradable polymers from renewable resources, the most notable of which is green plastic made from sugarcane-derived ethanol. In this case, sustainability is mainly achieved through a renewable resource, which promotes a low-carbon economy.

From sugarcane cultivation to the production of green polyethylene, each kilo of green polyethylene produced captures about 3.09 kilos of CO_2 (the life cycle assessment of green polyethylene cited by the FO), which is a calculation that considers the CO_2 gains and losses in all stages of the production process. The importance of green plastic is demonstrated in a comparison to previous data on naphtha, a traditional polyethylene.

CO_2 is captured from the atmosphere during sugarcane cultivation and remains fixed during the entire life cycle of green plastic products. To ensure that the green plastic produced is renewable, the world leader in analysing carbon isotopes conducts dating tests of the products across all lots at the FO (information gathered from a report by the FO).

Table 1
An overview of the interviewees.

Involvement in the supply chain of green plastic	Role	Country of origin	Data collection technique
Third stage	Production coordinator for the green PE manufacturing plant	Brazil	Personal interview
Third stage	Manager of institutional relations	Brazil	Personal interview
Third stage	Director of sustainability	Brazil	Personal interview
Third stage	Researcher in the innovation department	Brazil	Personal interview
Fourth stage	Coordinator in the sustainability department	Brazil	Online interview
Fourth stage	Coordinator of innovation	Belgium	Online interview
Fourth stage	Director of sales	Germany	Online interview

Source: Elaborated by the authors.

3. Theory

According to Schumpeter's 'vision', development is the result of spontaneous and intermittent changes that occur in the environment, which, in turn, form new combinations that represent the generated innovations (Schumpeter, 1982). Economic development happens to the existence of the entrepreneurial act, and the entrepreneur is responsible for carrying out the new combinations. In evolutionary theory and the interactive process, innovation is a complex procedure that occurs through internal organisational effort and an organisation's intra- and inter-firm interactions.

Organisations engaged in constant learning and innovation are more likely to gain advantages in competitive markets and organisational performance in the long run. Through product differentiation, organisations are creating products with reduced environmental impact during the life cycle, which indicates the participation of and interactions between various stages in the supply chain (Gonçalves-Dias et al., 2012; Stucki and Woerter, 2016).

The challenge of innovation is to work with nature's limited resources to produce economic growth and social prosperity, without compromising the needs of future generations. The call to better the environment motivates organisations to engage in research on clean and renewable raw materials. Replacing non-renewable with renewable resources is a key item on organisational agendas, as well as the subject of many public and private debates. Due to the attention they have received, renewable resources have become an economically viable alternative to traditional materials (Torresi et al., 2008).

Since the 1970s, discussions on sustainability have become more widespread. The main debate surrounds the three main dimensions of SD: economic, environmental and social. Some authors, such as Sachs (2008) and Pawlowski (2008), explored additional dimensions (such as cultural, territorial and political dimensions). The concept of SD comprises the idea that environmental, social and economic problems must be observed jointly, allowing for interfacing (Boons et al., 2013; Giddings et al., 2002; Hopwood et al., 2005; Iyer-Raniga and Treloar, 2000). According Steurer et al. (2005), an organisation is sustainable when it has sufficient income to pay taxes to public authorities, offer fair prices to suppliers, provide adequate salaries to its employees and distribute interests from creditors and dividends to its shareholders.

SCM promotes innovation that is based on sustainability (Carter and Easton, 2011; Carter and Rogers, 2008; Lii and Kuo, 2016; Linton et al., 2007; Matos and Silvestre, 2013; Pagell and Wu, 2009; Roy et al., 2004; Seuring and Muller, 2008; Silvestre, 2015a, b; Soosay et al., 2008). One organisation should play a leading role in dictating the course of the supply chain, stimulating other organisations to adopt SD. This organisation is referred to as the focal organisation (FO), an inducer of innovation in the supply chains to which it belongs (Carvalho and Barbieri, 2012). FOs are important for managing uncertain business environments in developing economies and for promoting learning in supply chains and innovation towards sustainability (Silvestre, 2015a, b).

In consideration of sustainability-oriented innovation, the literature has highlighted the concept of SSCM. In general, this concept involves characteristics of business sustainability (i.e. economy, environment, society, stakeholders, volunteers, resilience and long-term goals), and SCM characteristics (i.e. flow, coordination, stakeholders, relationships, value, efficiency and performance) (Ahi and Searcy, 2013). Several authors (e.g. Carter and Easton, 2011; Ahi and Searcy, 2013) have suggested that SSCM is the voluntary integration of social, economic and environmental aspects to create a coordinated supply chain. This supply chain manages the material, information and capital flows associated with the procurement, production and distribution of products, which ensures profitability, adherence to stakeholder requirements, competitiveness and organisational resilience (Dubey et al., 2017).

Based on studies by Linton et al. (2007), Ahi and Searcy (2013) and Leppelt et al. (2013), research by Dubey et al. (2017) defined SSCM as SCM with an emphasis on economic, social and environmental stability, highlighting its use in securing sustainable, long-term growth. In the present study, we focus on the concept of SSCM and its applications in traditional supply chains through the views of Dubey et al. (2017), Diabat et al. (2014) and Govindan et al. (2016).

Dubey et al. (2017) identified and classified the drivers of SSCM, including: green warehousing; strategic supplier collaboration; environmental conservation; continuous improvement; information technology use; logistics optimisation; internal and institutional pressures; social values and ethics; corporate strategy and commitment; economic stability; and green product design. These drivers were used to develop a theoretical framework explaining the complex interactions between variables in the dynamic environment of SSCM.

Faced by strict government regulations and intense global competition, organisations are pressured to implement sustainable practices that improve their environmental conservation efforts, such as launching economic welfare initiatives, paying attention to health and safety issues and encouraging employment stability (Diabat et al., 2014). The development of a more equitable, sustainable, post-fossil-carbon society requires the collaboration and engagement of a diverse group of stakeholders (Govindan et al., 2016; van Hoof and Thiell, 2014). Cleaner production practices can provide advantages through supply chain relationships, innovations and governance mechanisms, which can potentiate SSCM (Govindan et al., 2016; van Hoof and Thiell, 2014).

There are empirical and theoretical research opportunities concerning the operation of sustainable supply chains in a developing country, such as Brazil (Silvestre, 2015a, b). Cabralde et al. (2015) highlighted the interdependence of product innovations in external markets and the overall performance of Brazilian

organisations. Supply chains based on natural resources tend to be more geographically limited and prone to local social demands than traditional supply chains (Silvestre, 2015a, b). The increased demand for renewable products has intensified the need for innovative developments in the chemical industry (Carmo et al., 2012), such as green plastic.

4. Results and discussion

4.1. Green plastic production and requirements

The pilot plant started producing green plastic in May 2007 with a capacity of 2.5 kilos per hour. After these simulations were performed, adjustments and modifications were made to improve the process for use in industrial plants. With this increase in the green plastic production scale came a trial-and-error period, and improvements and adjustments were made based on this period (according to information obtained from one interviewee involved in the third stage [FO]). As Silvestre (2015a, b) highlighted, FOs play an increasingly significant role in managing this, encouraging learning along the supply chain and promoting innovation towards enhanced sustainability.

The main difference between traditional and green plastic production processes is the raw material used. For example, naphtha is used in traditional plastic, while sugarcane-derived ethanol forms green PE. In the production of green plastic, sugarcane metabolises carbon dioxide and produces sucrose through mechanised harvesting. The sugarcane net is fermented and distilled to produce ethanol. Oxygen is present in the formula of ethanol, which can cause problems in second-generation catalysts.

The competitiveness of plastic depends on oil and ethanol prices. Other aromatic products with market value can result from traditional plastic as surplus of the production process. In the green plastic production process, what remains is water and contaminants that require expenditures for wastewater treatment (third-stage [FO] interviewee).

In addition to the processing stage (first and second generations), the FO is studying the feasibility of merging the supply chain into an ‘integrated plant’ that is responsible for all stages, from planting sugarcane to biopolymer production, to reduce the costs incurred by the upstream stage (third-stage [FO] interviewee). One interviewee (third stage [FO]) noted: ‘Our vision is that there will be growth, since what the market will want is not only green polyethylene, but other renewable products’.

Considering that the technology for producing green PE is ready, the FO has initiated several biotechnological projects with strategic partners, including state and federal agencies. These projects seek alternatives to the use of ethanol as a renewable raw material to consolidate the company's leadership in the production of biopolymers (third-stage [FO] interviewee).

For the annual production of green PE (i.e. 200,000 tonnes), 65,000 ha of sugarcane plantations are required, which equals 0.2% of Brazil's arable land (third-stage [FO] interviewee). In 2003, the end of sugarcane burning and mechanised harvesting returned to the public agenda, due to societal, industrial and external market demands (Alves, 2009).

To respond to these demands, and meet sustainability requirements, the government of São Paulo, which is the largest producer of sugarcane in Brazil, signed a protocol of intent with the Brazilian Sugarcane Industry Association (UNICA) in 2007 and the Organisation of Sugarcane Growers in the Centre-South Region of Brazil (ORPLANA) in 2008, called the Agro-Environmental Protocol of the São Paulo Sugarcane Sector (Torquato and Ramos, 2012; Torquato et al., 2015). The Protocol established an elimination timetable for the burning and the mechanised harvest of sugarcane for the signatories (i.e. the industry and its suppliers), among other agricultural and environmental directives. The signatories that complied with these directives would receive the Green Ethanol Certificate, which recognises the organisation's commitment made to environmental conservation (Torquato and Ramos, 2012).

From the perspective of sustainability, the mechanisation of planting and harvesting sugarcane had some benefits, such as ending the pollution caused by sugarcane burning, reducing pain for field workers, increasing productivity and promoting the use of straw (use of sugarcane straw for the biomass production) as a source of energy and vegetation cover. However, investments in mechanisation are more common in their own and administered areas by the mills, due to the prohibitive cost of which make up the harvest fronts (Torquato et al., 2015).

4.2. Sustainability and innovation in the FO's supply chain of green plastic

Proximity in the supply chain is necessary for the achievement of common objectives. One organisation should fulfil the role of leader, establishing the path to be followed by other agents of the supply chain. In this sense, the FOs can induce innovation throughout the supply chain (Carvalho and Barbieri, 2012; Silvestre, 2015a, b).

The present research considered the effects triggered by the FO during the upstream and downstream stages (i.e. spillovers). Sugarcane planters and ethanol-producing plants operate in the stages prior to the FO's involvement, while plastic manufacturers, wholesalers, retailers and consumers comprise the demand chain (i.e. following the FO's involvement).

In green plastic production, the replacement of oil with sugarcane led to significant changes in the FO's supply chain, which had to be reorganised in terms of suppliers. Rail is considered the most sustainable mode for ethanol transport. Therefore, we observed that the code of conduct implemented by the FO's ethanol suppliers is the main upstream effect.

The code includes requirements related to burning, biodiversity, environmental practices, human and labour rights, and product life cycle. In 2011, the FO adopted a supplementary certification programme created by a British institution, which attests whether the sugarcane production is sustainable. Audits are carried out on sugarcane plantations, in ethanol plants and within the FO, which verify the use of sustainable practices throughout the supply chain. Compliance is verified through a systematic audit carried out by the FO in the power plants (i.e. ethanol suppliers) (third-stage [FO] interviewee).

The main downstream effect contributes to the environmental importance of green plastic. For organisations using the green plastic produced by the FO in their own products, a seal was created to guarantee the use of a renewable material, which can be considered one of the major downstream spillovers. This seal attracts consumers who recognise environmentally friendly production processes. In most cases, the use of green plastic adds value to the final product, which can offer a competitive advantage.

An interviewee from one of the manufacturing organisations involved in the fourth stage of the supply chain mentioned that the choice of green plastic added value to its brand, product and industry-wide image, which helps them compete in a market with a growing trend towards eco-friendly design. It includes the fact that society undergoes a reflection period on the impact caused to the environment, the maintenance of scarce resources and life quality. In another organisation involved in the fourth stage, green plastic is used in 5% of total production, but when recycled materials and other sustainable solutions are considered, this is closer to 30%. The interviewee from this organisation, which produces

packaging, also mentioned that its customers are very price sensitive in that a limited number of customers are willing to pay at all.

The following analysis considers green plastic through the lens of SSCM, with an emphasis on the FO and changes in the petrochemical industry. In the case of green PE, the technology needed for production was developed in the 1960s, but it had low viability due to its massive energy consumption and polymerisation of ethene (i.e. this technology was retrieved, comprising the production of ethene from ethanol, which has been enhanced in the case of green PE). In previous decades, the ethene derived from alcohol was not very pure, which hindered its use in second-generation processes (third-stage [FO] interviewee).

Green plastic can therefore be regarded as a process innovation (Marques, 2010). In 2005, studies aiming to improve the green plastic production process began. Research conducted by the FO was motivated by its customers, receiving financial assistance from one of its customers in Asia. In April 2007, the company used volatile raw material in its plastic resin for the first time (i.e. formula change, the oxygen component). Investments were made by the petrochemical company and, after several attempts, an ethene formula was reached through polymerisation (purity), and then the value was added to turn ethene into ethylene from a renewable source (third-stage [FO] interviewee).

The same process was used to produce traditional and green polyethylene, and the final products have the same features and characteristics. However, as the catalyst used in green PE production is very delicate, the ethene must be purified, which is the main difference between traditional and green processes. In addition to the benefits caused by the uptake of carbon dioxide, mainly due to the use of renewable raw materials, the production process of green plastic offers another advantage in the purity of the ethene obtained (99.99%), resulting in green PE (third-stage [FO] interviewee). Approximately half a billion Brazilian Real was invested into the green plastic project, part of which was assigned to research and development (R&D) of renewable raw materials besides sugarcane (third-stage [FO] interviewee).

The commercial launch of green PE occurred in 2010, along with the creation of the seal 'I'm green™'. This seal is used in products using green PE and addresses plastic manufacturers and their customers. It represents the added value for the agents of the fourth stage in the supply chain, as green PE creates sustainable features in the final product, aligning with the FO's strategy to create value through the production of renewable polymers. The FO's marketing and customer control departments for renewable products monitor the use of this seal through an agreement between all parties. Manufacturers may use the seal so long as they follow several requirements that ensure environmental sustainability.

The FO has also identified their prospects, especially in foreign markets. As of 2012, the largest manufacturers using green PE were located in France, Germany and Japan, comprised mainly of those producing packaging and automotive parts. Due to increased product demand, US manufacturers are increasingly interested in green PE. About 80% of the green PE produced by the FO is exported (third-stage [FO] interviewee).

We did not identify any innovations regarding the physical distribution of green PE, which is the same for petrochemical plastic. Due to the change of raw material (i.e. naphtha to sugarcane-derived ethanol), transportation is a significant aspect of green PE production, and is mostly achieved by rail. The FO has long-term contracts with its ethanol suppliers, which is the second stage. When it comes to logistics, half of the shipments arrive through the Santos and Paranaguá Ports, operated by the governments of São Paulo and Paraná, respectively. The rail modal corresponds to another part of the flow of ethanol production. Rail transportation is growing significantly, more often to the Rio Grande Port/RS in Brazil for export, thereby reducing production costs (third-stage [FO] interviewee).

By analysing the third stage of the supply chain from a theoretical perspective, we can observe that the FO's policies on sustainability are based on the three main dimensions of SD (i.e. economic, social and environmental), with considerations towards political and cultural biases, to achieve its organisational vision: to be the world leader in sustainable chemistry by 2020.

The FO's business strategy is based on the principles of sustainability. The 2020 vision, which reflects the challenges in SD, include ten strategic and operational performances objectives: 1) ensure security in chemistry, work and processes; 2) produce superior economic and financial results, as it is one of the largest thermoplastic resins producers in the world; 3) offer post-consumer solutions, such as plastics recycling; 4) become a major global producer of thermoplastic resins using renewable resources; 5) promote water efficiency; 6) mitigate climate change by reducing GHG emissions through the use of renewable raw materials; 7) ensure efficiency through the promotion of renewable energy; 8) contribute to the improvement of local human development; 9) develop environmental and social solutions through such methods as customer support; and 10) strengthen practices that contribute to sustainable development (information gathered from a report by the FO).

Climate change necessitates the development of green technologies and the pursuit of operational efficiency to decrease GHG emissions. While the FO is responsible for a significant level of emissions, considering the supply chains in which it is involved, the FO elaborates GHG inventories concerning its productive activities and initiates projects to improve its energy use. As a petrochemical company, the FO uses naphtha as its main input. However, the company actively invests in R&D for technologies and innovations that consider the increasing demand for renewable raw materials (information gathered from a report by the FO). The FO is conducting research on alternative raw materials for producing renewable plastics in partnership with international laboratories, universities and organisations (third-stage [FO] interviewee).

Regarding its economic development, the FO aims at increasing competitiveness (i.e. in relationship with its customers and suppliers), expanding productivity (e.g. operating industrial plants more efficiently), improving logistical and supply performance, reducing costs and achieving financial results. The company gained some achievements related to the internationalisation of its business and operations, as demonstrated by its organisational capabilities within the global petrochemical industry (information gathered from a report by the FO).

5. Conclusions

Climate change has intensified the demand for better social and environmental conservation efforts, motivating organisations to become more engaged in the development of sustainable technologies. The call for renewable products has pressured the chemical industry to respond with innovative solutions. Under this backdrop, the present study sought to investigate the innovation process in green plastic production, a process which replaces a non-renewable resource for a renewable one, through the lens of SSCM.

It was found that, during the first two stages of the supply chain, sustainability is being considered in the expansion of sugarcane production. For the supply chain of green plastic, a code of conduct was created from a series of social and environmental requirements, which must be followed by the FO's suppliers. From the examples provided of the FO's practices, it was evidenced that the FO's sustainability policies are based on the three main dimensions of SD: economic, environmental and social.

The present study identified differentiations between green and petrochemical plastics, such as ethene purification for green PE production to be viable and the creation of the 'I'm green™' seal, and also found evidence of increased rail transport to receive ethanol and attract potential consumers of green PE. During the fourth stage of the supply chain, it was evidenced that the use of green plastic meets consumer requirements concerning sustainability, enhancing the FO's image regarding their environmental impact.

Based on the theoretical discussion, it is possible to verify which upstream and downstream effects were triggered by the FO when producing green plastic. Considering the upstream spillovers present, it can be concluded that the replacement of raw material caused significant changes to the supply chain. Sugarcane cultivation increases carbon dioxide capture, thereby reducing GHG emissions. It is inferred that the code of conduct implemented by the FO's ethanol suppliers was the most significant upstream effect. The main downstream effects contribute to the environmental importance of green plastic. The FO identified potential consumers and created the 'I'm green™' seal for them, which can be considered the main downstream spillover. In most cases, the use of green plastic adds value to the final product, which offers a competitive advantage.

The results show that collaborations between the FO and the other agents of the supply chain are important for the development of green plastic. Many initiatives created by the FO were implemented to support the production of green plastic throughout the industry, such as certification programmes and seal of quality/approval. These initiatives also aim to reduce the social and environmental impact along the supply chain.

There is a need for a wider view of production chains that consider the use of renewable raw materials. Further research should be conducted with other agents of the supply chain to gain a comprehensive understanding of the production process. To assess the environmental gains and losses caused by production, future studies that accompany the life cycle analysis of green plastic should be conducted. In the context of Brazil, the present study highlights the need for policies that consider science, technology and innovations based on renewable raw materials, aiming to establish Brazil as a prominent player in the international chemistry sustainable.

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